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Wireless Broadband Systems (Wireless ATM)*

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Summary

Broadband systems are generally those systems which provide an especially high transmission rate. An exact definition of this term can be found in ITU Recommendation I.113 which characterizes broadband services as having a higher required transmission rate than a primary multiplex connection in ISDN (2048 kbit/s).

A brief overview of the current state of development of wireless broadband systems is given below. This is followed by important aspects of the development of wireless ATM systems for movable and mobile stations.

1 European Research in Broadband Systems

The importance of wireless broadband systems is evident from the number of projects being carried out in this field, e.g., within the European research programme ACTS [1] [2].

ACTS/MEDIAN: Wireless LAN at 60 GHz transmitted from ATM cells

ACTS/MagicWAND: Indoor wireless ATM system at 5 GHz

ACTS/OnTheMove Mobile multimedia value-added services

ACTS/SAMBA: Cellular ATM broadband system at 40 GHz

ACTS/CABSINET: Cellular interactive multimedia communications system for metropolitan areas (at 5, 17, 40 GHz)

ETSI/RES 10: HIPERLAN 1 (wireless LAN with 23 Mbit/s at 5 GHz

ETSI/BRAN: Broadband wireless access networks which also support ATM

ATM Forum: TCP over ATM, MPEG over ATM, wireless ATM;

DAVIC/LMDS: Digital and Video Council/Local Multipoint Distribution System

ATMmobil: Key development project of German ministry of research and technology: development of wireless ATM systems (at 5, 19, 40, 60 GHz)

Until 1995 the EU research programmes RACE [2] I und RACE II were devoted to the development and testing of prototypes of systems with broadband radio transmission.

From 1992 to 1994 the RACE II programme promoted the development of third-generation mobile radio systems with the objective of integrating GSM, DECT, paging, mobile satellite radio and trunked mobile radio systems along with their different applications into a universal mobile radio system (*Universal Mobile Telecommunications System*, UMTS) with data rates up to 2 Mbit/s. This effort included the development of standardized terminals and an expansion of services with high data rates [8].

Along with these systems which were designed to provide a high degree of mobility, the RACE II project MBS *(Mobile Broadband System)* undertook the development and testing of a technology and system concept for a wireless ATM system at 60 GHz which demonstrated the possibility of video transmission with a 16 Mbit/s transmission rate (net) at a 50 km/h speed of movement [22].

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[1] *Advanced Communication Technologies and Services*

[2] Research and Development in Advanced Communications Technologies in Europe

1.1 MBS

The RACE II/MBS project undertook studies of techniques for linking mobile terminals to stationary broadband networks with data rates at the multiplex radio interface of up to 155 Mbit/s. Narrowband services were also to be provided. The MBS system made a particularly important impact and convinced the professional world of the possibility of providing the services of broadband ISDN to mobile users through wireless ATM transmission [19, 5, 14, 21, 24].

In addition to providing a link-up to the broadband ISDN, the MBS concept also supports a cooperation with other systems such as UMTS. The type of network and level of integration can vary all the way from a privately-operated MBS system with a low level of service integration and mobility up to a public MBS system with a high level of integration, extensive mobility and coverage to a widespread area [4]. Figure 1 shows MBS in relationship to other systems with differing levels of mobility support for their terminals and transmission rates. It can be seen that MBS combines the wide-ranging service spectrum of broadband ISDN with the mobility of mobile radio networks whilst offering the services of narrowband systems such as UMTS, W-LAN, GSM, DECT and their derivatives for Radio in the Local Loop (RLL) applications.

Due to the flexibility of MBS and the availability of the services of B-ISDN a variety of different applications are possible. These are indicated (with no claim to completeness) according to the data rates required and the mobility of their users (see Fig. 2).

The author and his colleagues were responsible for designing the radio and network protocols for MBS which, although they were not implemented in the demonstrator, were incorporated into a number of successor projects in the ACTS programme and developed further (see Section 1.2). For example, MBS was the first time an ATM-based broadband radio interface was proposed for mobile use and specified in parts of the system [26, 20].

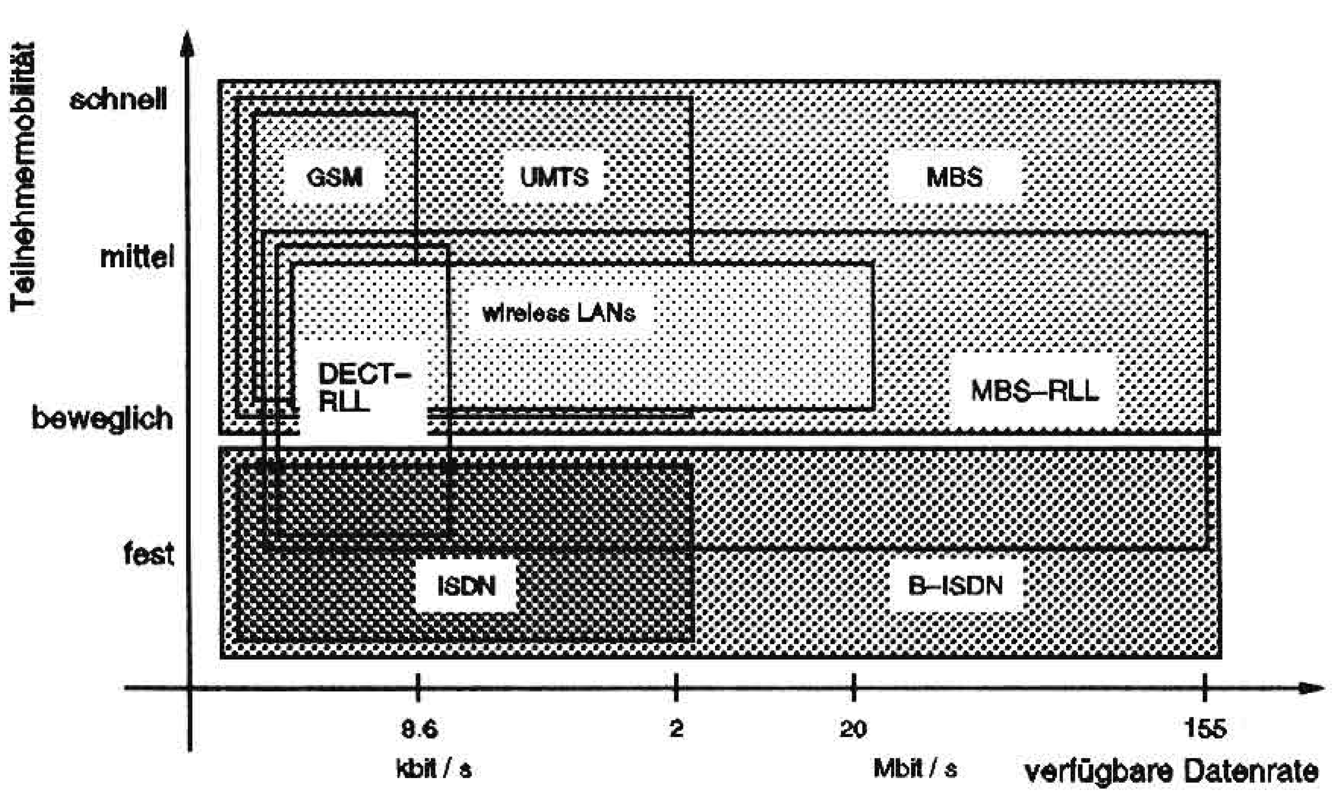

Figure 1: MBS and other data networks

1.2 Wireless Broadband Communications in the ACTS Programme

As the successor to RACE II, the ACTS research programme [3] of the European Union is conducting field trials and demonstrations in order to monitor the systems which have been developed as they are used in real applications.

Along with the advanced development of UMTS, the promising attributes of MBS are being developed further in the following ACTS projects

1.2.1 MEDIAN

MEDIAN *(Wireless Broadband CPN/LAN* (Customer Premises Network) *for Professional and Residential Multimedia Applications)* develops transmission technology at 60 GHz for wireless networks with data rates of up to 155 Mbit/s for multimedia, voice and video applications.

The goal is to develop a demonstration system for multimedia applications, including research into modulation, channel coding, channel access methods and a cooperation with ATM fixed networks with high data rates. MEDIAN will provide mobile users with access to B-ISDN through the transparent transmission of the ATM cells of B-ISDN over the radio interface.

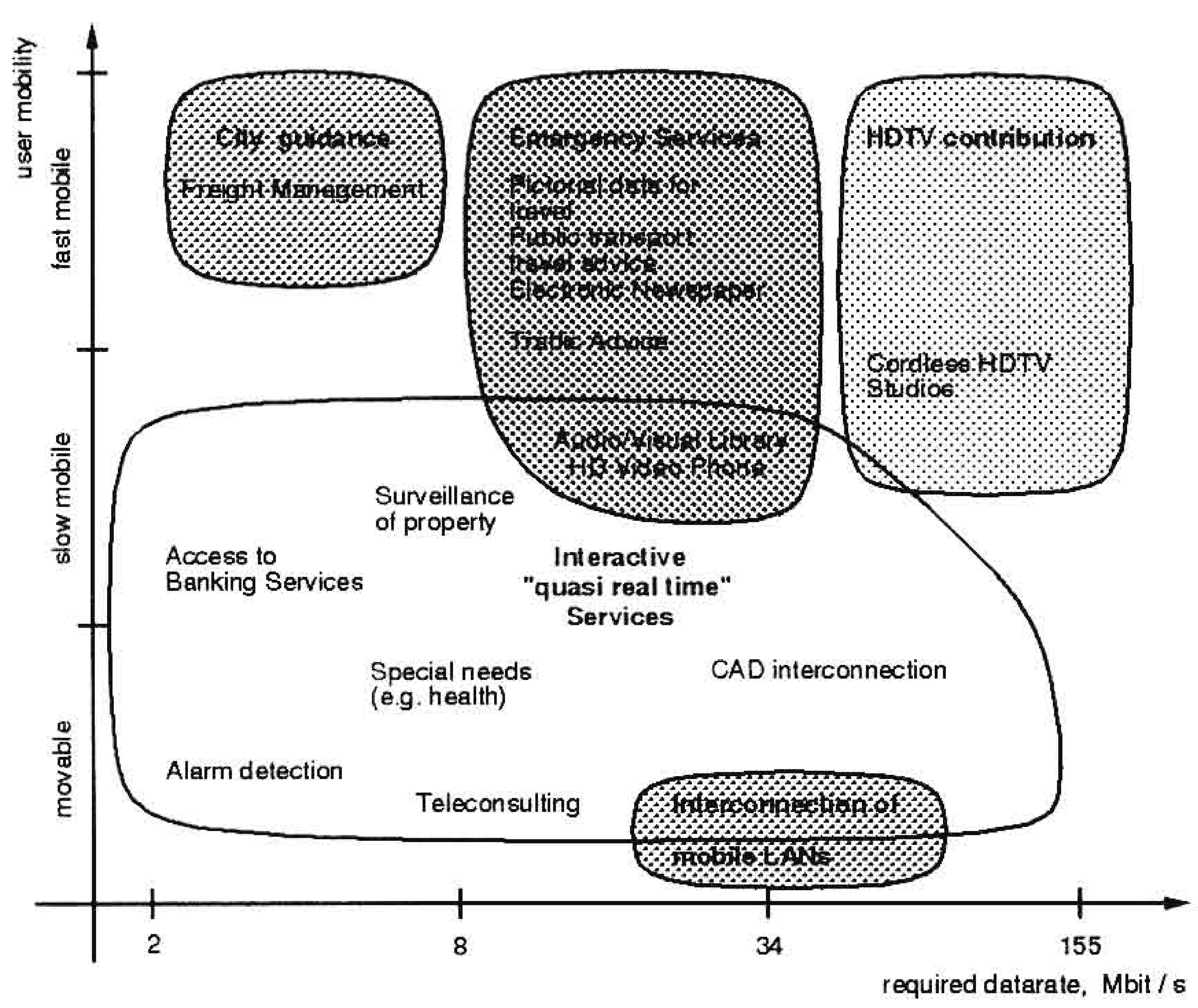

Figure 2: MBS applications and services

1.2.2 Magic WAND

WAND *(Wireless ATM Network Demonstrator)* will extend the use of ATM technology to mobile users and examine realistic user environments. The field of application covers Internet services over ATM in indoor areas with a 20 Mbit/s transmission rate at 5 GHz. The project will demonstrate an indoor wireless ATM demonstration network.

The emphasis will be on modelling the radio channel and developing channel access protocols as well as new control and signalling functions which are to be submitted to ETSI for consideration as a basis for a standard for wireless ATM systems.

1.2.3 SAMBA

SAMBA *(System for Advanced Multimedia Broadband Applications)* aims to expand the ATM fixed network through the use of a cellular radio access network in order to provide mobile users with access to broadband multimedia applications. Mobile ATM terminals will then be able to have access to services comparable to those used by terminals in the ATM fixed network. Therefore, besides the development of the system elements, the main priorities of SAMBA are integration with the ATM fixed network and mobile support. A demonstration system at 40 GHz is being created which can provide transparent ATM links with transmission rates of up to 34 Mbit/s net for all ATM categories of service.

In contrast to other ACTS broadband projects, the time-critical ATM services CBR and VBR will also be supported and the appropriate provisions made for radio protocols so that the radio channel will appear to offer a quality of service comparable to a fibre optic transmission path (within the framework of ATM quality of service requirements). A demonstrator system will be shown at the Expo in Lissabon in September 1998.

The SAMBA project is also developing technology not yet provided by the ATM Forum for call handover between different ATM fixed network access points. The author and his staff members are responsible for the implementation of the protocols of the radio interface and of the ATM network protocols, using their experience from MBS (see Section 1.1) [16, 17].

1.2.4 AWACS

The AWACS *(ATM Wireless Access Communication System)* project is further developing a system based on the NTT/AWA system and is developing a demonstrator to support terminals with limited mobility and provide public access to the ATM fixed network. The system operates in the 19 GHz range and provides users with user data rates of up to 34 Mbit/s.

In addition to developing the demonstrator, AWACS is carrying out extensive research in the areas of channel and source coding, intelligent antennas, optimization of LLC protocols, 40 GHz transmission technology and mobility management.

1.2.5 AMUSE

AMUSE *(Advanced Multimedia Services for Residential Users)* is specifying and developing a demonstrator for advanced multimedia services to link residential customers to an ATM infrastructure. The services will be offered under real conditions through the use of different technologies such as HFC *(Hybrid Fibre Coax)*, ADSL *(Asymmetrical Digital Subscriber Line)*, FTTC/FTTB *(Fibre to the Curb/Building)* and WLL *(Wireless Local Loop)*.

A possibility is being developed for setting up end-to-end links to different access networks. Moreover, the individual field tests are being linked over the European ATM network.

The project will be set up in two phases: services such as *Video on Demand* (VoD), *News on Demand* (NoD) and high-speed Internet access in the first phase; other services will be offered in the second phase.

1.3 ATMmobil

This programme of the German Ministry of Research and Technology is involved in the development of concepts and the corresponding demonstrators for four forms of wireless ATM systems.

The concept ATM-RLL *(Radio in the Local Loop)* promotes using ATM point-to-multipoint line-of-sight radio at 26/40 GHz to bridge the last few miles in a local area network.

The second concept (W-ATM LAN) is examining the wireless connection of mobile computers to support multimedia applications at 5 and 19 GHz.

The third concept (cellular W-ATM) links mobile terminals with an ATM radio interface over a cellular network at 5 GHz to an ATM broadband network.

The fourth concept (*Integrated Broadband Mobile System*, IBMS) involves the development of wireless transmission technology for indoors and outdoors. Along with infrared as the medium for indoor purposes, millimetre waves at 5, 17, 40 and 60 GHz are being used. Adaptive antennas, single-carrier transmission technology, radio interface, radio resources and mobility management are the focus of the research being undertaken.

Similar to UMTS for mobile radio systems with multiplex transmission rates of up to 2 Mbit/s at the radio interface, an integrated concept for the individual concepts mentioned above is being pursued within the framework of ATMmobil. The author is heading up the ATMmobil systems group, his staff members are participating in the implementation work of the second and third concept and are also involved in the ETSI-BRAN standardization.

As was visible at the ACTS Mobile Summit in Rhodos, Greece in June 1998, up to now no W-ATM project has reached a status to be able to demonstrate a fully operational air interface.

1.4 The Role of the ATM Forum in the Standardization of Wireless ATM Systems

Although the ATM Forum is not an official standards body, it is playing an important role in the quasi-standardization of certain forms of the ATM fixed network through its association with industry and its products. In June 1996 the ATM Forum became involved in WLAN standardization. The WLAN group originally wanted to focus its attention on mobility support by ATM fixed networks, a project which was supposed to run until the first quarter of 1999 [18]. There are now indications that the radio interface will also be addressed. Based on the experience of 1998, the anticipated market for wireless ATM systems is already so large that the standardization of the radio interface for worldwide use will not only be left up to Europe (ETSI).

1.5 The ETSI Contribution to ATM Standardization

The standardization group ETSI RES 10 (*Radio Equipment and Systems*, RES), now ETSI BRAN *(Broadband Radio Access Networks)* is currently developing a family of standards referred to as HIPERLAN *High Performance Radio Local Area Network* for wireless broadband communication at 5 and 17 GHz. There are four different types of HIPERLAN:

HIPERLAN Type 1 is a standard for wireless communication between computer systems in close proximity to one another.

HIPERLAN Type 2 refers to wireless access to ATM fixed networks with a multiplex bit rate of 25 Mbit/s for W-ATM LANs.

HIPERLAN Type 3 is also referred to as HIPERACCESS. It is an application in HIPERLAN Type 2 technology for outdoor distances of up to 1 km (W-ATM RLL).

HIPERLAN Type 4 at 17 GHz is also referred to as HIPERLINK. It will offer rates of up to 155 Mbit/s for short distances for the connection of W-ATM systems.

The ETSI BRAN *(Broadcast Radio Access Networks)* group is standardizing the radio interface [7] (see Fig. 3).

Table 1 presents a comparison of the key features of all four systems.

2 Services in Broadband ISDN

Multiplex data rates of up to 155 Mbit/s on the wireless user connection are necessary for the integration of wireless broadband applications in B-ISDN. These kinds of applications require services for continuous interactive data as well as for bursty-type interactive data. Along with voice transmission, applications with continuous bit streams include video conferencing in which real-time requirements also must be

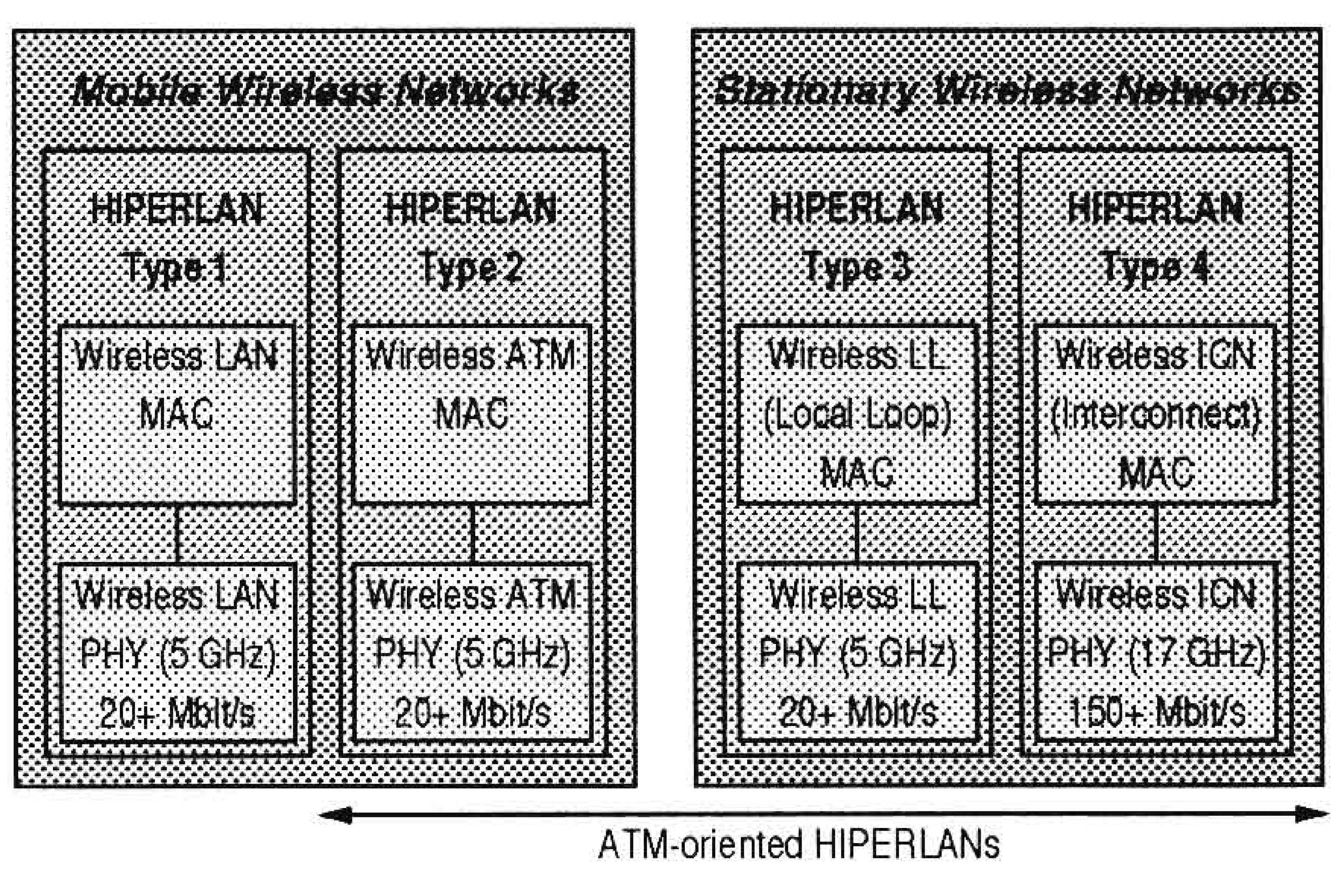

Figure 3: The four different types of HIPERLAN

Table 1: Parameters of the ETSI BRAN HIPERLANs

HIPERLAN Wireless	Type 1 LAN	Type 2 ATM	Type 3 Local loop	Type 4 Point-to-point
Carrier freq.	5 GHz	5 GHz	5 GHz	17 GHz
Network top.	decentral	central	PTP	PTP
Antennas	omni	omni	lobe	directional
Cell type	pico	pico	cigar"	radio relay
Area of applic.	ind./outd.	ind./outd.	outd.	ind./outd.
Operator	private	private/public	private/public	private
Mobility	port./move.	port./move.	stationary	stationary
Backbone	LAN	B-ISDN, ATM	ATM network	B-ISDN
Data rate	20 Mbit/s	24 Mbit/s	48 Mbit/s	155 Mbit/s
Comm. range	50–100 m	50–100 m	5000 m	50-500 m
Product	1998	2000	after 2000	after 2000

strictly maintained. Interactive services are characterized by a wide fluctuation in the requirements for bit rates. Thus a short information request to a database can result in a very long response requiring a high transmission rate. A distinction is made between the following:

- Interactive services
  - Telefony
  - Video telephony
  - Broadband video conferencing
- Inquiry services
  - Access to databases
  - Radio, TV, HDTV, Video-on-Demand
  - Electronic newspaper
  - Videopost
- Data communications
  - LAN links
  - Filetransfer
  - CAM links
  - High-resolution video transmission

Synchronous transmission methods (*Synchronous Time Division Multiplexing*, STDM) have difficulty coping with the varying requirements of broadband services. Although an oversizing of the transmission capacity of synchronous channels reduces waiting times, it results in a poor utilization of capacity in the transmission medium. ATM technology *(Asynchronous Transfer Mode)* is better suited to dealing with the demands of broadband services.

2.1 ATM As A Transmission Technology in B-ISDN

Asynchronous Transfer Mode (ATM) is the connection-oriented packet-switching method used in B-ISDN. ATM combines the advantages of connection and packet-oriented switching, specifically the statistical multiplexing of data from different connections to one medium and the message switching of packets in the network nodes between the communicating terminals. The data streams to be transmitted are divided into short blocks of a fixed length referred to as ATM cells. The cells of different connections are transmitted with time interleaving over a physical channel. Depending on their data rates, the connections are dynamically allocated varying amounts of transmission capacity, with some of them transmitting a large number of cells per time unit and others only very few. The cells in each connection are transmitted in the order of their arrival.

The ATM multiplexer adds empty cells to the multiplex data stream if none of the connections requires transmission capacity and a synchronous transmission method is being used (see Fig. 4).

2.2 ATM Classes of Service

The number of protocols required for the ATM adaptation layer has been kept to a minimum through the classification of services into four different groups according to the parameters time relationship between source and sink, bit rate and type of connection. Time-continuous services with constant or variable bit rates are differentiated according to those which are

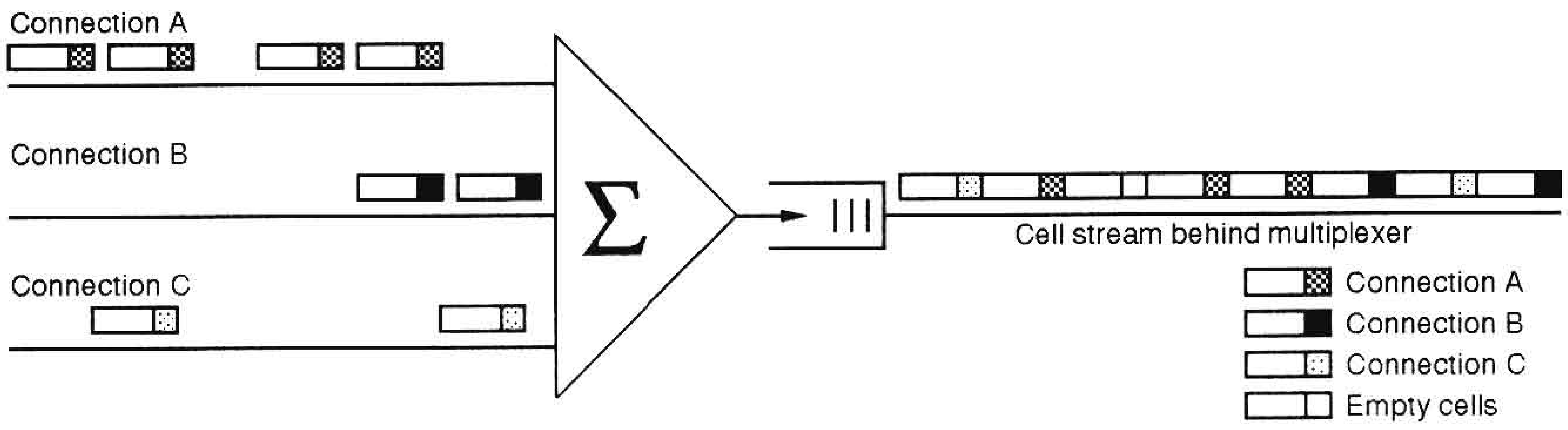

Figure 4: Statistical multiplexing of cells to a medium

connection-oriented and those which are connectionless.

In accordance with the class of service, control data is also added to the user information. This is used to allow the restoration of user information which is divided among several cells. The control data is generated by the SAR sublayer when the data is divided into cells. In the receiver the corresponding SAR sublayer must join the data together in the correct sequence according to the control data.

For identification of the sequence of the individual ATM cells each message contained in a cell is assigned a sequence number to enable the receiver to detect the loss of any cells. Whereas the sequence number is available with all the classes of service, additional backup data and different segment types are only being planned for some of the classes. Due to the varying control data part, the user data part is 44 – 48 bytes [23].

In its specification *Traffic Management (V 4.0)* [9] the ATM Forum differentiates between different classes of service which represent different applications. The specified quality of service parameters for the following classes of service are listed in Table 2:

Unspecified bit rate: No quality of service parameters are specified for the UBR class of service. No guarantees are provided for this class, which means that it only benefits from a *best effort service.*

Available bit rate: The ABR class of service is particularly suitable for applications which are not real-time-oriented and also have no requirements in terms of transmission rate. Only the cell loss rate is defined as a parameter for the quality of service.

Constant bit rate: The CBR class of service is planned for real-time-oriented services with constant bit rates which have a high requirement for *cell loss ratio* (CLR), *cell transfer delay* (CTD) and *cell delay variance* (CDV).

Non-real-time variable bit rate: The VBR class of service is a compromise between the VBR and ABR classes of service. This is used for applications which require more quality of service guarantees than the ABR class but attach no importance to the assurance of a specific variance in cell transmission times (CDV).

Real-time variable bit rate: Real-time-oriented applications which place a high demand on delays and their variance as well as on cell loss rates require a real-time VBR service.

2.3 Functions and Protocols of the AAL

Because transmission errors cannot be completely prevented even with fibre optic technology, an end-to-end error correction procedure dependent on type of service is provided in the AAL layer.

The AAL protocols type 1 and type 2 are used for the real-time-oriented CBR and VBR services. They supply their *protocol data units* (PDU) with sequence numbers and check sums to aid in the detection of lost or incorrectly inserted ATM cells. An FEC procedure can be used as an option to correct bit errors [12]. If the bit error probability in the ATM layer exceeds the correction capabilities of the code used, something which can particularly occur from time to time on a radio transmission path, then the quality of service requested by the user cannot be guaranteed by this procedure.

An ARQ protocol based on the functions for detection of bit errors and cell loss in the lower AAL sublayers (*Common Part Convergence Sublayer*, CPCS and *Segmentation and Reassembly*, SAR) is provided in the highest sublayer of the AAL (Service Specific Convergence Sublayer, SSCS) in AAL protocols type 3/4 and type 5 [10]. According to [11], these ARQ proto-

Table 2: Classes of service and their quality of service parameters

Attribute	ATM Layer Service Classes				
	CBR	VBR(RT)	VBR(NRT)	ABR	UBR
CLR	×	×	×	×	—
CTD	×	×	×	—	—
CDV	×	×	—	—	—

CBR	Constant Bit Rate	VBR	Variable Bit Rate	UBR	Unspecified Bit Rate
RT	Real-Time	NRT	Non-Real-Time	ABR	Available Bit Rate
×	specified	—	unspecified		

cols can be executed efficiently with a packet loss probability of 10^{-3}. If the packet loss probability for packets 1 kbyte in length is to be maintained, then the bit error probability 10^{-7} cannot be exceeded. The bit error probability of a radio transmission path protected by an FEC procedure usually lies above that limit and is therefore too high for an ARQ procedure to be carried out efficiently in the AAL.

3 Architecture of the ATM Radio Interface

Figure 5 illustrates the schematic structure of a cellular ATM mobile radio system [6, 22]. The access points to the ATM fixed network are located between the *Radio Access System* (RAS) and the ATM fixed network. Each access network contains one or more transmit and receive facilities *(transceiver)* as well as a *base station controller* (BSC) which carries out the protocols of the base station. The UNI interface is usually provided between the RAS and the ATM network.

This radio networks offer wireless ATM access from moving or mobile *wireless terminals* (WT)

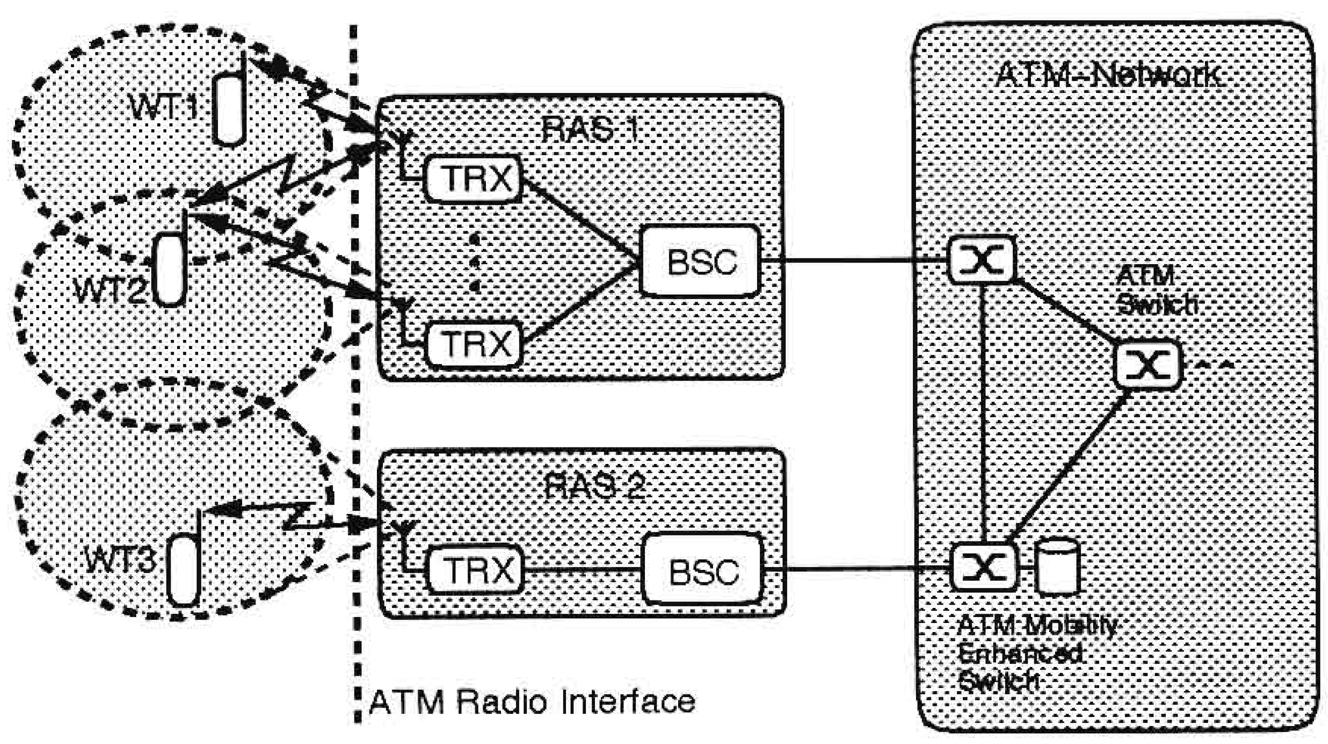

Figure 5: Architecture of a cellular ATM mobile radio network

in selected areas, e.g., in buildings, outdoors or in the vicinity of buildings.

3.1 The Radio Access System as A Distributed ATM Multiplexer

Wireless local area networks (W-LAN) are a typical application for cellular ATM mobile radio networks. With limited operating time (because of battery-based power supply) and reduced data rates (because of radio transmission), it is desirable to provide wireless terminals in W-LANs with the same services available to ATM terminals linked to a fixed network. In particular it should be possible for all ATM applications to be used without any need for modification, i.e., in wireless as well as in wired terminals based on the same AAL services.

Figure 6 clarifies how AAL protocols are end-to-end transport protocols because they are only operated between terminals and do not occur in the network nodes. Transmission over the ATM radio interface takes place within the ATM layer with the help of individual ATM cells, with the influence effects of the radio interface remaining hidden from the service users of the ATM layer (the entities of the AAL). This is referred to below as transparent transmission of ATM cells. From the standpoint of the user, the terminals of a radio cell which operate virtual connections over the RAS behave as if they were connected over a cable to an ATM multiplexer (see Fig. 6).

3.2 Frequencies for W-ATM Systems

The 5.15–5.25 GHz frequency band is currently being provided for W-ATM systems in Europe and in the USA, although CEPT has allocated this band to HIPERLAN 1. The FCC in the USA makes reference to *High-Speed Multimedia Unlicensed Spectrum.* WRC is still studying the problems involved. There are national problems with the 5.25–5.3 GHz expanded HIPERLAN band due to the original usage and in the USA

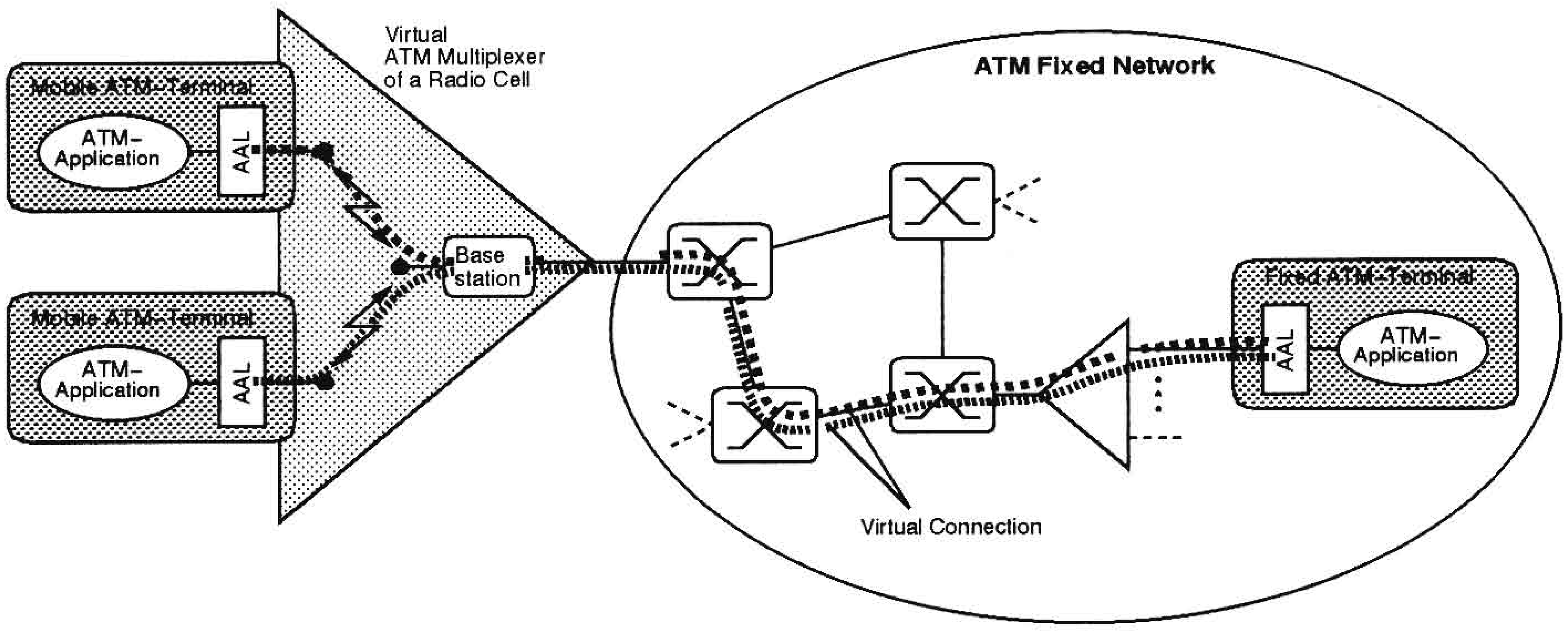

Figure 6: Connection of a cellular ATM radio network to an ATM fixed network

in the entire 5.25–5.35 GHz band. WRC99 will probably be allocating the entire 5.15–5.87 GHz band for use by broadband local radio networks. Bands already being used will have to be reallocated for use by broadband radio networks; this is called *refarming* a band. Because of the large number of different systems (old and new), anticipated systems must ensure that they have the ability to coexist.

3.2.1 Transmission Procedures for W-ATM Systems

Because a high multiplex transmission rate of approx. 25 Mbit/s at the wireless interface is being sought, DS-CDMA *(Direct Sequence Spread Spectrum Code Division Multiple Access)* procedures will not be appropriate because of the bandwidth required. Newer demonstration systems use *Orthogonal Frequency-Division Multiplexing* (OFDM) with symbol-by-symbol parallel signal transmission over 16 or 64 FDM carriers on the downlink and with some systems also on the uplink. In addition, 64 QAM and hybrid modulation methods are used. Capacity is usually distributed in the frequency and time domains (FDM, TDM, FDMA, TDMA, FDD, TDD). Recent experiments have involved using adaptive antennas for the prevention of interference and improvement to quality of service. *Space Division Multiple Access* (SDMA) can also be used for this purpose.

3.3 Protocol Stack for the ATM Radio Interface

Compared to the fixed network, the radio interface as a distributed ATM multiplexer requires that certain radio-specific aspects also be considered:

Radio propagation: E.g., diffraction, shadowing, reflection and multipath propagation.

Channel access: Coordination of access to shared-use radio channels for implementing the transmission sequence of the ATM cells specified by the scheduler function of the RAS.

Error protection: Unreliable transmission conditions on radio channels necessitate the use of error protection schemes to fulfill the quality of service requirements of the individual virtual connections according to the different categories of service.

The quality of service required on a radio path is ensured whereby, along with AAL error protection measures, a data link control protocol (ARQ protocol) is used directly at the radio interface in the LLC sublayer to guarantee transparency in relation to the AAL. An ARQ protocol specific to the class of service is used which permits error protection in the LLC layer to be adapted to the individual requirements of each separate virtual connection over a separate access point per ATM service class.

Figure 7 shows the resulting protocol stack at the radio interface *(Wireless UNI)* which consists of a physical layer that considers the characteristics of the radio transmission (*wireless physical layer*, W-PHY) and a *data link layer* (DLC). The DLC layer consists of a sublayer for the coordination of channel access (*medium access control*, MAC) and a sublayer which controls the logical channels and contains the error protection functions (*logical link control*, LLC).

The protocol stack shown in Figure 8 is currently being discussed by ETSI BRAN. Along with the W-ATM terminal, a W-ATM access

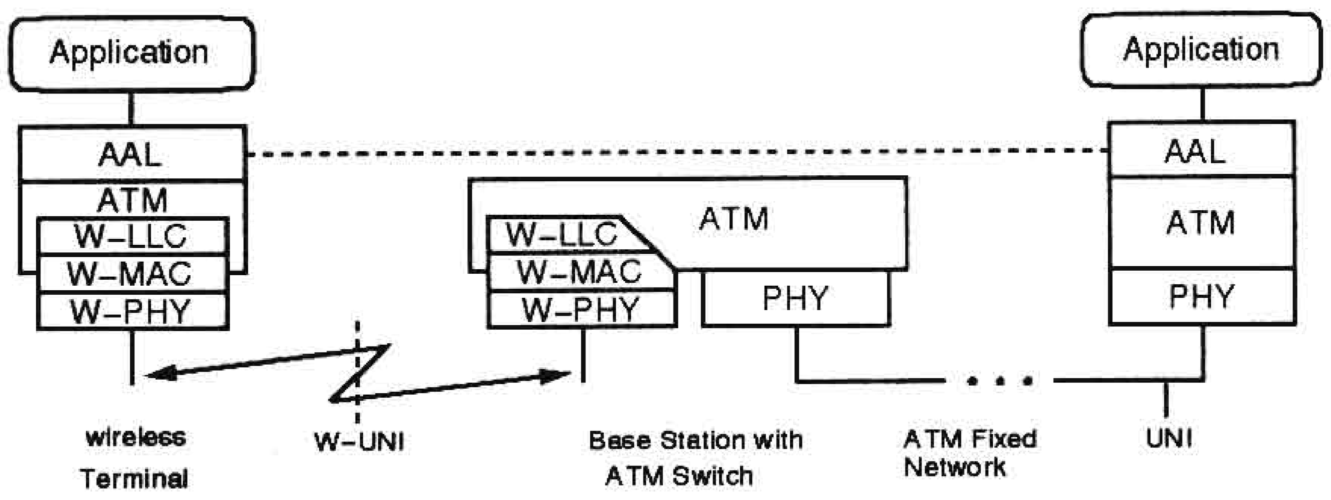

Figure 7: Protocol stack for the ATM radio interface (user plane)

in accordance with the capacity requirements of the terminals.

Most approaches consist of access to the shared physical channel being coordinated by a central entity, the base station. It carries out the dynamic allocation of transmission capacity to the terminals in the form of time slots, introducing a system of priority in which connections with high quality of service requirements are given priority. The base station therefore requires information on the number and the class of service of the ATM cells waiting for transmission in the terminals.

At the radio interface the base station produces a distributed ATM multiplexer which is created by a buffer and a sequence controller *(scheduler)* in the multiplexer: The terminals buffer the cells waiting to be transmitted; the base station controls the sequence of the cells being transmitted over the radio channel and also considers whether the cells received with errors should be retransmitted.

Sending a signalling message on the downlink, the base station identifies which future time slots following the signalling message on the uplink are available exclusively to a terminal for transmission. Likewise other time slots for downlink transmission are declared at certain terminals, thereby producing a period structure (see Fig. 9). All information which occurs in the upcoming period is stipulated within a signalling message, followed by the signalling message for the next period.

A period always consists of a downlink and an uplink transmission phase. In the downlink data transmission phase information is transmitted from the base station to the terminals within a reserved time slot; in the uplink data transmission phase, the reverse occurs. The length

point and an ATM switch which has been expanded to include mobility support are shown. The ITU-T signalling based on Q.2931 is located above the *signalling ATM adaptation layer* (SAAL), whereas applications are based on the AAL-X (X= 1, 2, ..., 5). Two layers at the radio interface (R) – the data link control layer and the physical layer – are responsible for safe transmission with error recovery.

3.4 Channel Access

In wireless ATM networks several users have to share the same physical channel. Access to the medium must be coordinated accordingly. In the projects described in Section 1 and in other company-specific work groups (worldwide) different channel access protocols have been developed and proposed for consideration in the ETSI/BRAN standardization. The approach incorporated in these protocols is discussed below.

Through the use of TDMA the physical channel is divided into time slots of the same or of varying length. Within these time slots signalling information and ATM cells with user data are exchanged between a mobile terminal and the base station controller. The allocation of transmission capacity is carried out dynamically

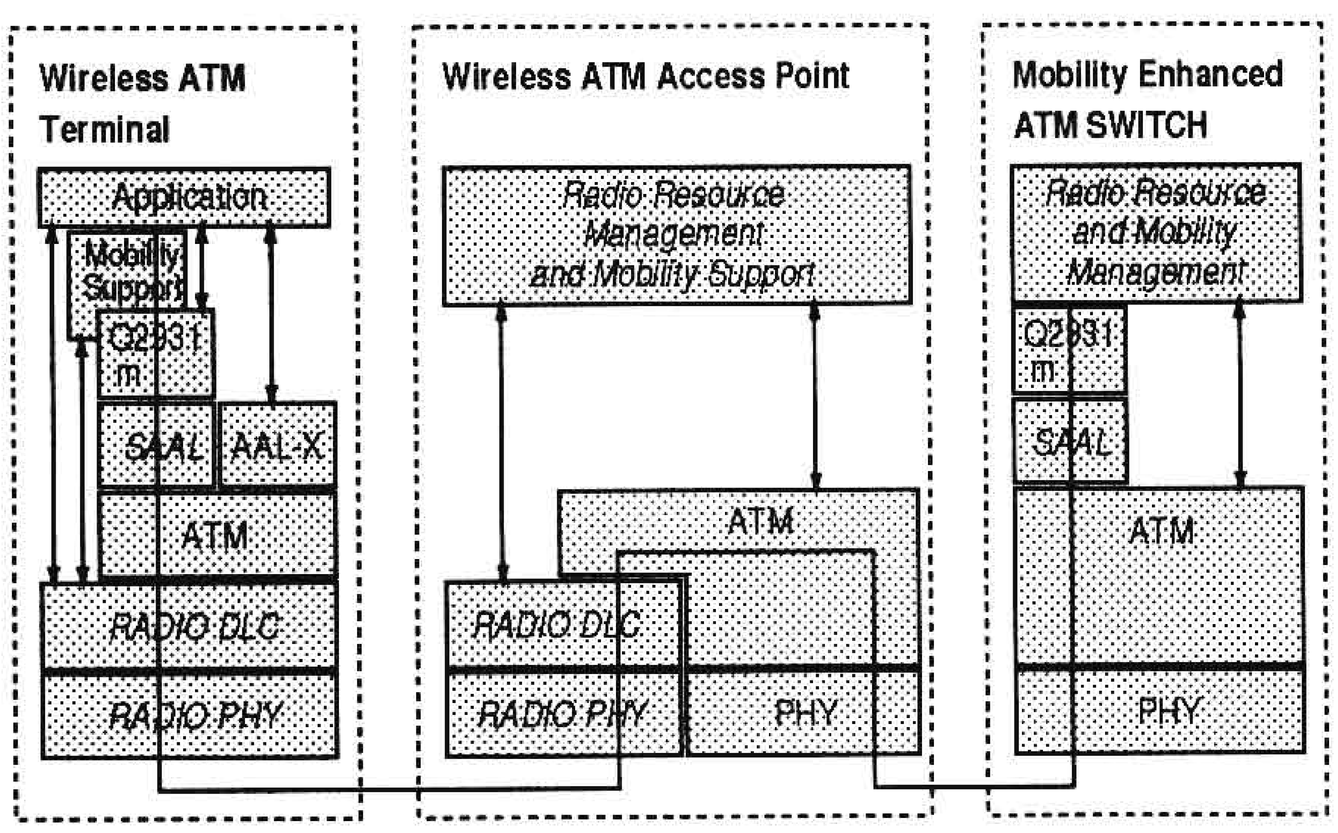

Figure 8: HIPERLAN/2 layers and architecture

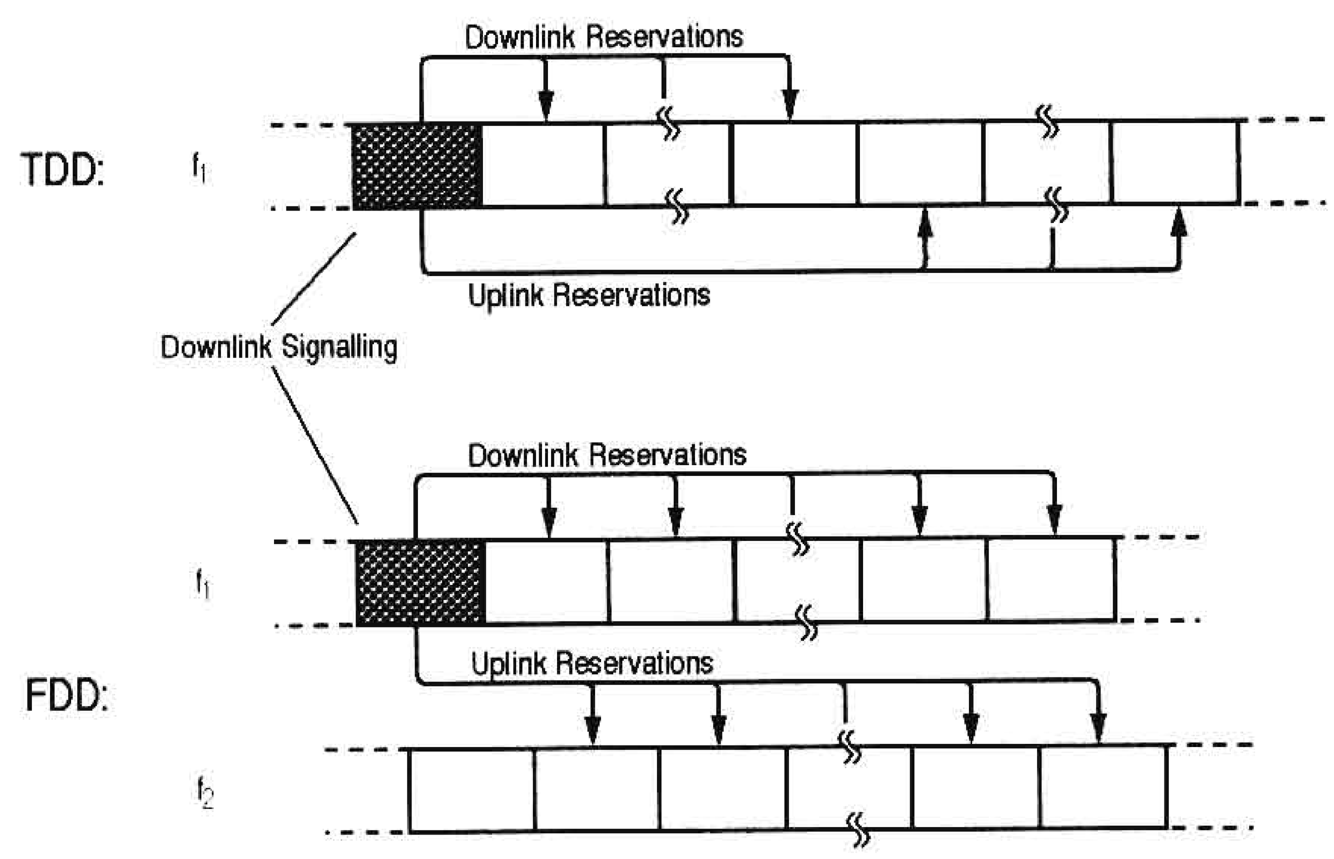

Figure 9: MAC signalling using TDD and FDD

of a period can be variable on a constant or a dynamic basis. The ratio of the duration from the uplink to the downlink data phase can be variable or constant. A variable ratio makes it easier to take asymmetrical traffic relationships into account, thereby resulting in a better utilization of channel capacity of the radio medium.

Either TDD or FDD can be used for the directional separation of a transmission (see Fig. 9).

Requests for capacity (e.g., number of waiting cells) can be transmitted piggy-back with ATM cells during the uplink data phase or through signalling time slots on the uplink which can be reserved for the different terminals or used in random access. Since a signalling time slot is short compared to an ATM cell because of the message length being submitted, partial time slots can be used. Restricted because of the radio range, a W-ATM base station usually only serves a small number of active terminals at any one time. Therefore a reservation-based *polling* method can be suitable for the transmission of capacity requests from terminals to the base station.

3.5 The LLC Layer

A radio channel is a transmission medium with a high level of packet error frequency on the scale of 10^{-3}. Since even real-time-oriented services have higher requirements than that, all services will need protection against transmission error.

There is a selection of three different methods:

- FEC *(Forward Error Correction)* – error protection through error detection and correction at the receiver side;
- ARQ *(Automatic Repeat Request)* – error recovery by packet retransmission in case of an error detected;
- recovery in combination with FEC.

The third form with the physical layer of the protocol stack of the radio interface taking over the function of *Forward Error Correction* is the one most commonly used. An ARQ procedure which protects connections from transmission error is provided in the *Logical Link Control* (LLC) layer.

3.5.1 Cell Discarding

Conventional ARQ protocols are suitable for services which are not time-critical. With time-critical services the maximum transmission delay of data packets should also be taken into account, because there is no point in transmitting a delayed packet which is taking transmission capacity away from the other waiting packets. The sender should transmit all data packets successfully before exceeding the allowable transmission delay. When it can be foreseen that this will not be possible with some of the packets, then they no longer need to be transmitted and should be discarded. A distinction is made between two different scenarios:

1. A packet was discarded before it was transmitted.
2. A packet is to be retransmitted because it was requested again.

In the second case, the data packet has already been assigned a sequence number which is known to the receiver. The receiver must therefore be informed of which packet has been discarded or else it will block the transmission and not forward all the subsequent packets to the next higher layer because one of the packets in the sequence is missing.

3.5.2 Connection Admission with ATM Radio Interfaces

If the packet train model is followed and physical connections are only set up for the duration of need, then the connection admission controller must ensure that for each accepted virtual connection each new train is guaranteed to receive a physical channel with only a short delay. Therefore the mechanisms familiar from ATM networks appear to be directly transferrable.

If the decentral organization of an ad hoc network is selected, then the connection admission control entity is implemented on a distributed basis. A relevant proposal can be found in [25].

In the W-ATM applications being anticipated, VBR services requiring real time support (see Table 2) will only make a relatively small demand on capacity utilization. If the plan is to interrupt the physical channels reserved for ABR services at any time despite the packet trains being run, then it can be expected that the quality of service of these services will be guaranteed.

4 Mobility Support for W-ATM Systems

The architecture of a broadband mobile radio system uses an ATM network as the transport platform. An ATM network contains no mobility support functions such as location management of mobile users or handover support. Figure 10 presents a typical W-ATM protocol stack for the control plane [15]. Appropriately for an ATM fixed network, the standard protocol for user network signalling (UNIsig, [13]) is supported for call control (CC) in the *fixed control plane* (see shadowed areas). The radio access system is transparent for these protocols. Protocols for radio resource management (RM) and mobility management (MM) are supported in the *wireless control plane* within the radio access system (*Mobility and Resource Management Protocol*, MRP).

4.1 Radio Handover

Radio handover *(Radio handover)* takes place between two transceivers (BST) of the same base station (see Fig. 11). The virtual connections are switched over within the *base station controller* (BSC), independently of the ATM fixed network.

A handover can be divided into three stages:

1. **Measurement of radio resources:** A handover is normally executed because of poor transmission conditions and the subsequent unsatisfactory quality of service of the radio channel. The conditions can only be assessed if measurements are conducted frequently enough. It is also necessary for the effects of radio propagation to be recognized and taken into account. This necessitates not only measurements of the actual connection but also those of the alternative radio channels.
2. **Handover decision:** This is the stage when it is decided whether a handover should be excecuted. The relevant algorithm uses as its criteria the measurement values provided of the radio conditions and the capacity utilization of the radio cells.
3. **Handover execution:** The signalling protocol is executed at this stage in a handover to enable the relevant MAC connection to be switched from one radio cell to another.

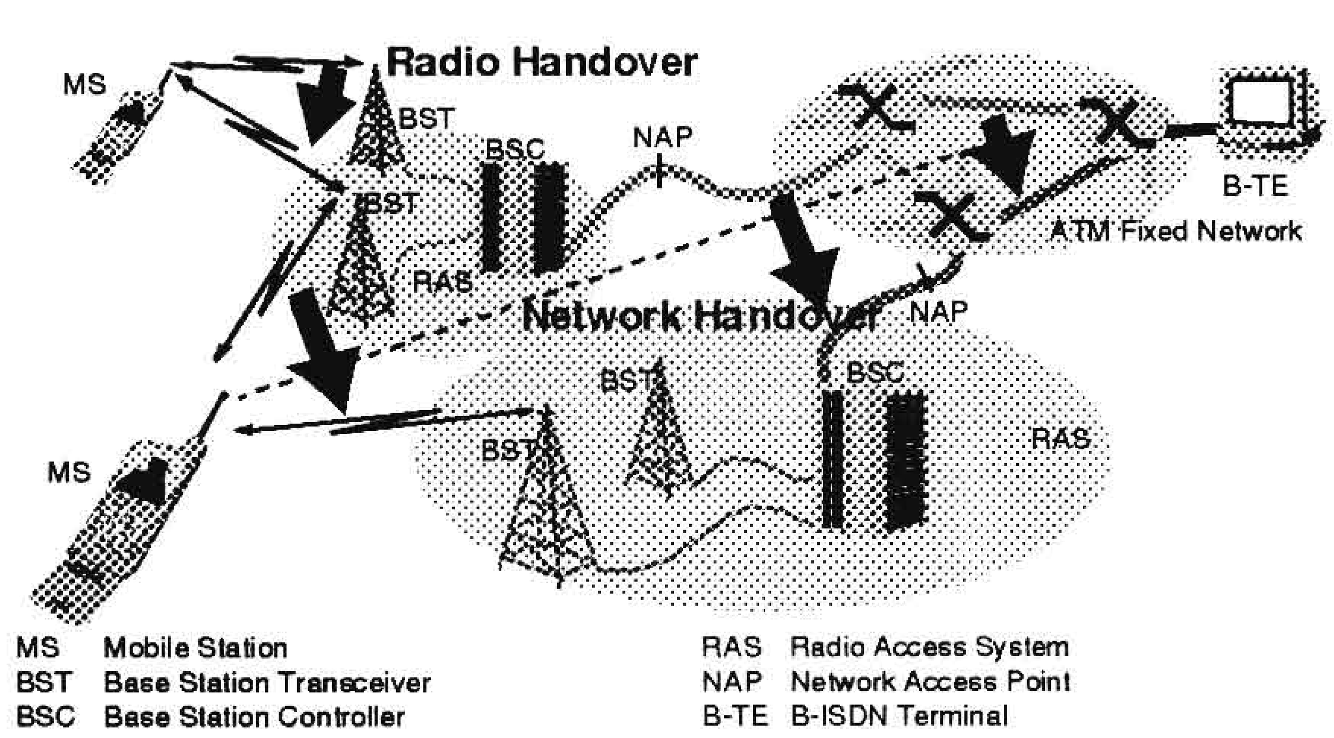

Figure 11: Radio and network handover in wireless ATM

Wireless ATM systems have the advantage that terminals and base stations are able to initiate handovers independently of one other. A terminal can initiate a handover because of receiving conditions; a base station can force a terminal to execute a handover (forced handover) if the receiving conditions or cell load require it.

There are two types of handover initiated by a terminal. If the handover is carried out during the actual connection, it is called a *backward handover.* If the connection has already been interrupted or is very poor, the handover signalling must be carried out over an alternative channel of the medium (*forward handover*).

4.2 Network Handover

During each network handover a change in route is necessary for any virtual channel connection in the fixed network which is not being supported by current ATM networks (see Fig. 11). A possible solution is transferring the switching function to the ATM layer. The actual switching is then carried out by an enhanced ATM switching centre with mobility functions which is therefore also referred to as an *(ATM Mobility Enhanced Switch*, AMES). In this case the virtual end-to-end channel connection remains intact (see Fig. 12). Consequently only an end-to-end connection is available for call control in the network. Otherwise no transition functions or adaptation functions are required between subnets. The role of the bridging function is more difficult to accomplish in the AMES because the standard stipulates asynchronous transmission and the ATM cells are not numbered. Therefore with each network handover there is the danger of ATM cells being lost.

A network handover in the ATM layer requires the rerouting of the virtual end-to-end channel connection in the VP or the VC switch within the ATM layer of the ATM fixed network.

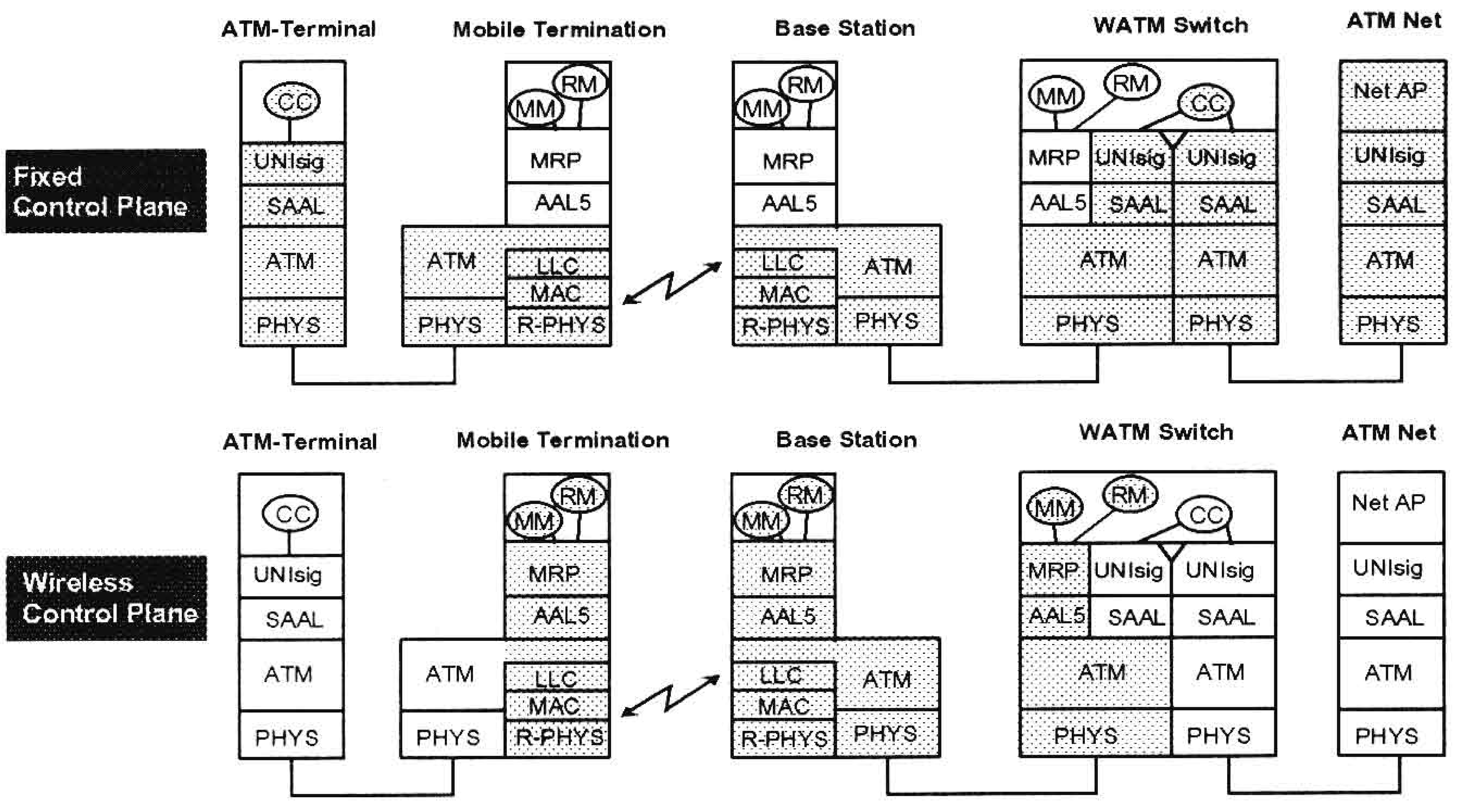

Figure 10: Protocol stack in wireless ATM

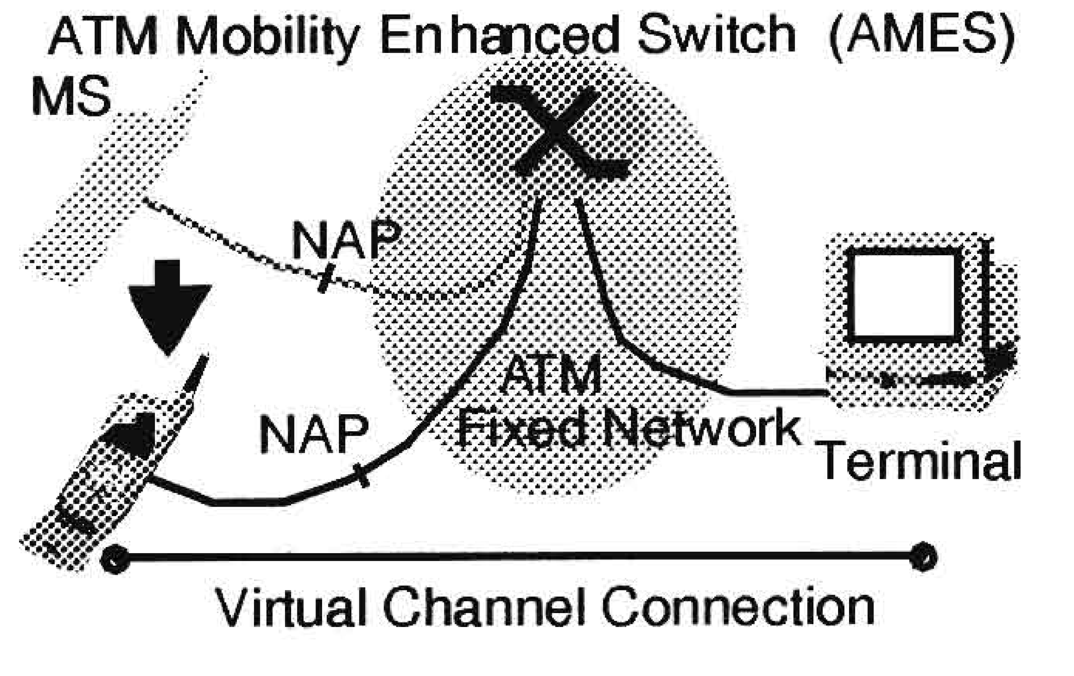

Figure 12: Network handover support in the ATM layer

Two typical concepts for executing a network handover are presented below. They are based on the rerouting of a virtual channel connection.

4.2.1 Virtual Tree

With backward handover protocols, in a network handover the mobile station deregisters from the old radio access system (RAS), which consists of a BSC and several BSTs, before it changes to the new RAS. Therefore in preparation a virtual channel connection can be set up to the new radio access system over the AMES which is currently carrying out the connection. The end-to-end connection will then be switched to that system during the network handover.

With forward handover protocols, it is not possible for the AMES to be informed in advance. The mobile station registers over the radio interface with the new radio access system which must then set up a new virtual channel connection to the AMES. The amount of time needed for setting up a new ATM network connection is in the region of 100 ms per ATM network element. Therefore, depending on the network topology, values into the region of seconds can accumulate. Connection setup times of this magnitude during network handover cannot be offset by the network through intermediate storage and accelerated transmission and instead lead to an interruption to service. Depending on the handover frequency, connection setup and termination place an additional burden on an ATM fixed network because of the signalling traffic and switching involved.

A service without interruption can be guaranteed through pre-reserved virtual channel connections between all RASs and the AMES. They can then be used immediately during network handover and produce the respective connection setup. However, each RAS must then constantly maintain reserved virtual channel connections to the AMES. This produces a socalled virtual connection tree (see Fig. 13) for each connection from a mobile station to AMES. Every virtual branch of this tree consists of two virtual channel connections (one per each transmission direction) which on their part consist of a chain of virtual channels between ATM network elements. In Figure 13 the virtual branches are abstracted as a direct line.

A virtual tree is set up for each call and continues to exist for the duration of an entire call. Only the virtual branch of a tree carries user data whereas all other virtual branches are unused. Although they are set up, i.e., all entries in the routing tables of the ATM network elements are available, they do not transmit ATM cells. In a network handover the virtual branch of the new radio access system is used whereas the old virtual branch is idle but continues to exist.

In AMES this changeover must be supported by a switching function which is carried out differently depending on transmission direction. There are various concepts for this [1, 26]. Virtual trees tie up additional capacity in a fixed network because all branches must provide the quality of service required for an RAS.

4.2.2 Extension of Virtual Channel Connections Between Radio Access Systems

Instead of the routing between different virtual branches being switched over, a virtual channel connection can be extended through the execution of a network handover which includes the extension of the circuit section between the old and the new radio access system. The new radio access system then takes over the function of the AMES.

When a connection is being set up, the location area of the mobile station establishes the first radio access system as the anchor for the entire connection. If a network handover occurs, the virtual channel connection is extended bidirectionally from the anchor to the new radio access system. In each subsequent network handover another extension is added between each old RAS and the new one, thereby producing a chain of extensions such as the one shown in Figure 14. The route can be shortened again in a network handover when the mobile station changes back to the previous RAS.

Here too a distinction has to be made between backward and forward handovers. In the first case, the extension can be set up before the change in radio access system. In the second

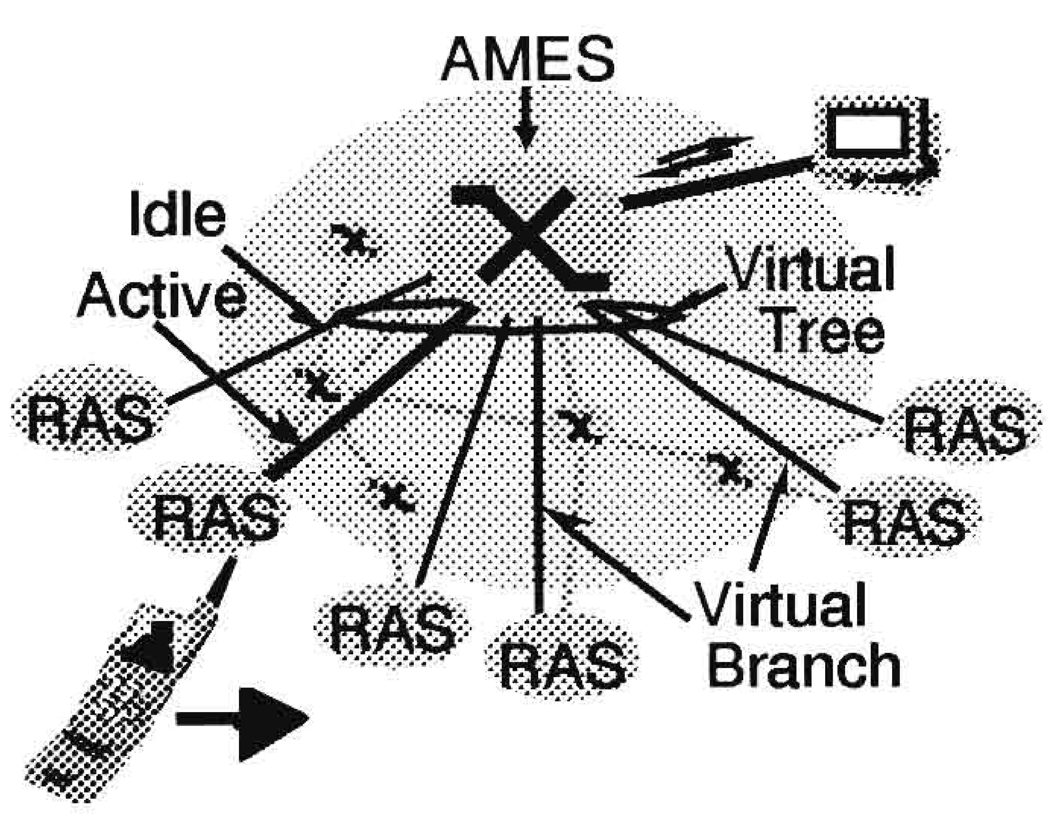

Figure 13: Virtual connection tree

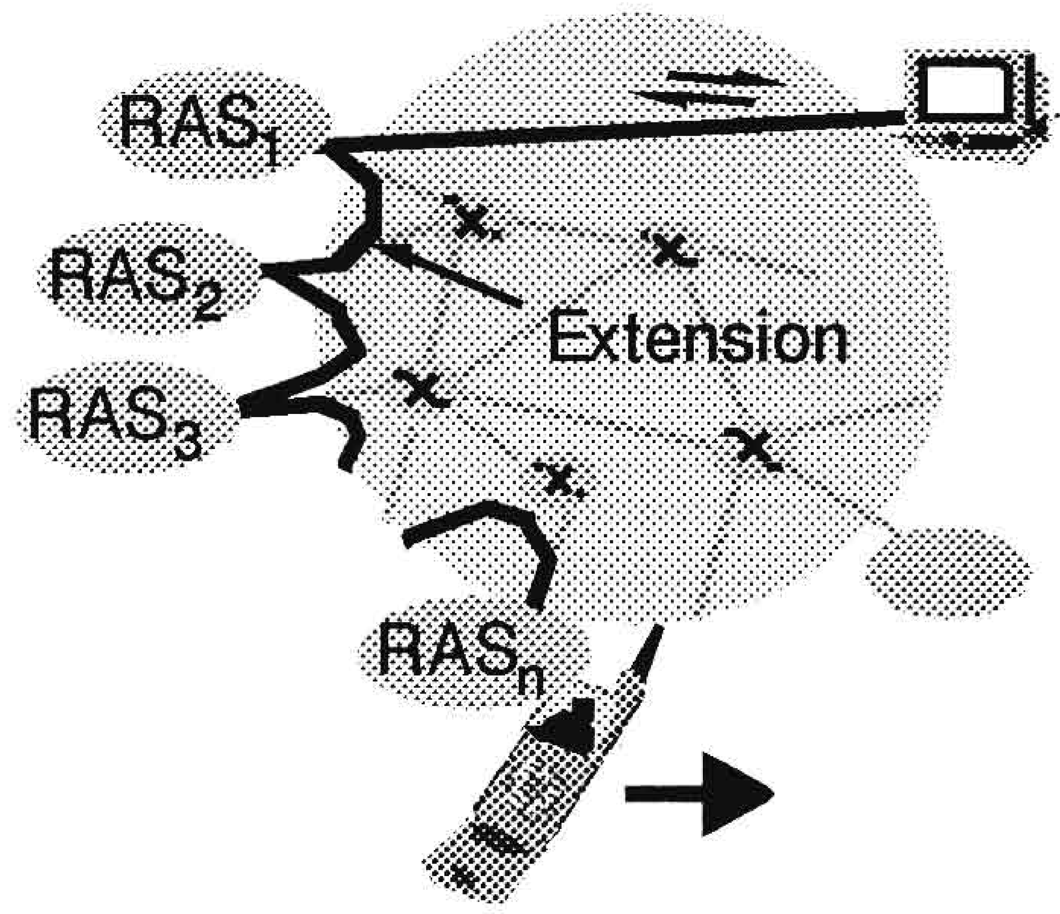

Figure 14: Extension of virtual channel connections

case, the extension of the bidirectional virtual channel connection to the old radio access system must be set up after the radio handover by the new radio access system.

As discussed in Section 4.2.1, this kind of connection setup can result in an interruption to service, which explains why it makes sense to use reserved virtual channels between neighbouring RASs. Similar to the virtual tree, as a precaution for each communicating mobile station a bidirectional virtual channel connection should be set up to each neighbouring RAS which could be used in a network handover.

4.2.3 Guaranteed Quality of Service

For network handovers in wireless ATM systems it is essential that the quality of service for the respective ATM connection be maintained. The procedures given as examples in the previous sections allow the execution of an accelerated network handover through the use of preset channels. These concepts on their own, however, cannot guarantee that the quality of service agreed at connection setup is also maintainable during a network handover.

It is clear from Figure 15 that ATM cells in a virtual tree can be lost during a network handover. In a forward handover the AMES is notified by the new radio access system (RAS 2) that a handover has taken place. The AMES thereupon switches over the virtual channel connection to the new branch of the tree. ATM cells remaining on the old branch after a handover go missing (cell 3 in this example). It is obvious that the number of lost cells is dependent on the data rate of the service and on the duration of the handover signalling.

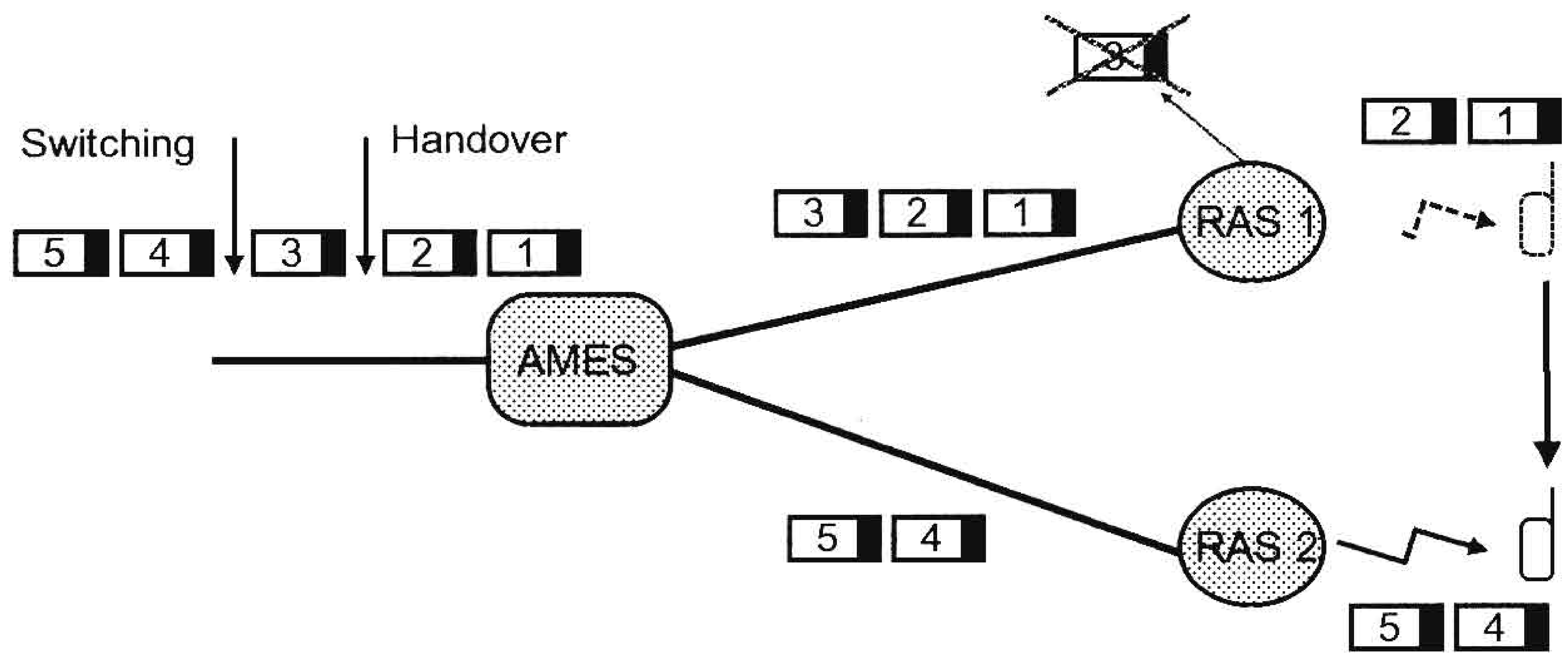

Figure 15: Cell loss during handover in a simple virtual tree

Protocols which have a minimal effect on quality of service during handover are currently at the specification stage. It is generally not possible for the quality of service of the ATM fixed network to be guaranteed in all situations in a mobility-supporting wireless ATM system.

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